Canopy structure from above and below: relations between hemiphots and satellite-based images

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Outline

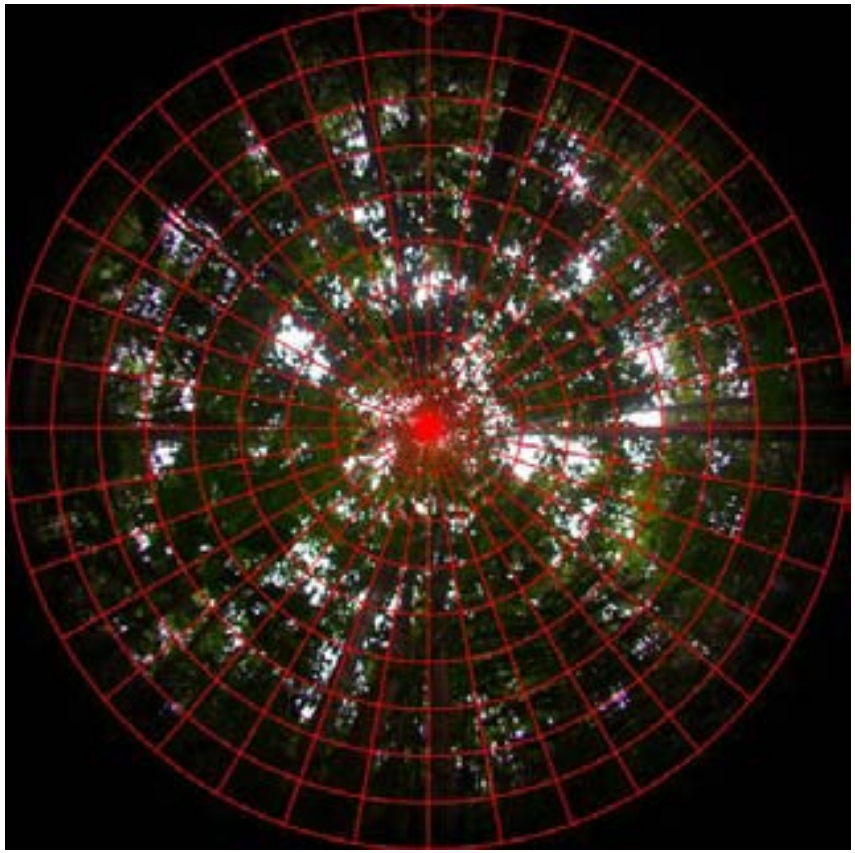
Context

- Competition for light, a critical process for forest dynamics.
- Light availability at local scale strongly depends on **canopy structure**:
  the spatio-temporal organisation of the morphological elements that compose the upper vegetation layer.
- Studied through various techniques:
  - *direct*, by manipulation of physical elements
  - or *indirect*, by estimation of integrative properties.

Hemispherical photographs "Hemiphots"

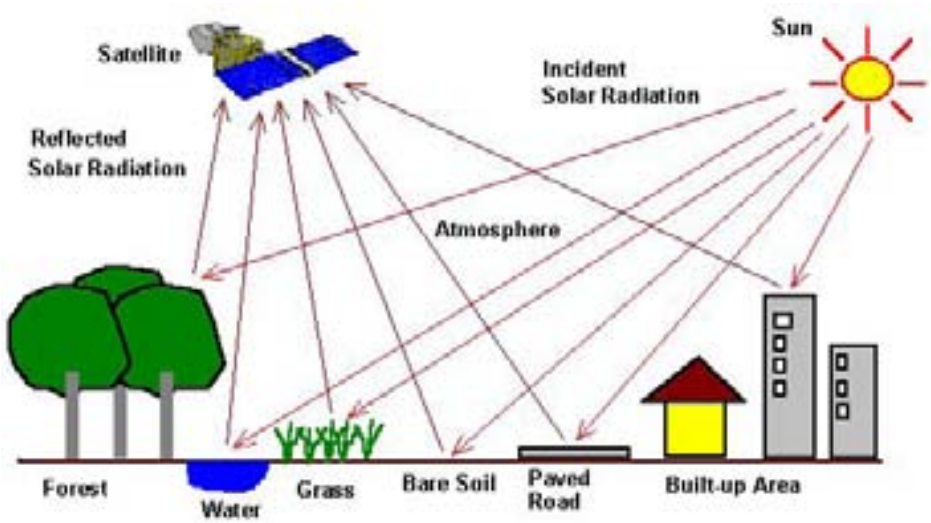
Three types of data can be obtained:

1. canopy openness and Plant Area Index,
2. duration of sunflecks,
3. incoming solar energy.



Relatively easy to achieve, but time-consuming, subjective thresholding.

Remote sensing



http://maps.unomaha.edu/Peterson/gis/notes/RS2.htm

- Repetitive data acquisition,
- Variable spatial range and resolution,

- Object analysis in tropical forests:
  stand structure (Wittman *et al.*, 2002), diameter growth of tree crowns (Clark, 2004), mortality rates of emergent trees (Clark, 2004), detection of skid trails, logging damage and small scale gold mining sites (Gond *et al.*, in press).

Few studies on canopy properties at very local scale.

Aim

- Study the *structure* of the canopy of a tropical forest and its *spectral properties* at *very local scale*,
- Adress the potentiality of Ikonos images to characterize canopy structure and provide information about lighting conditions under forest cover.

Question

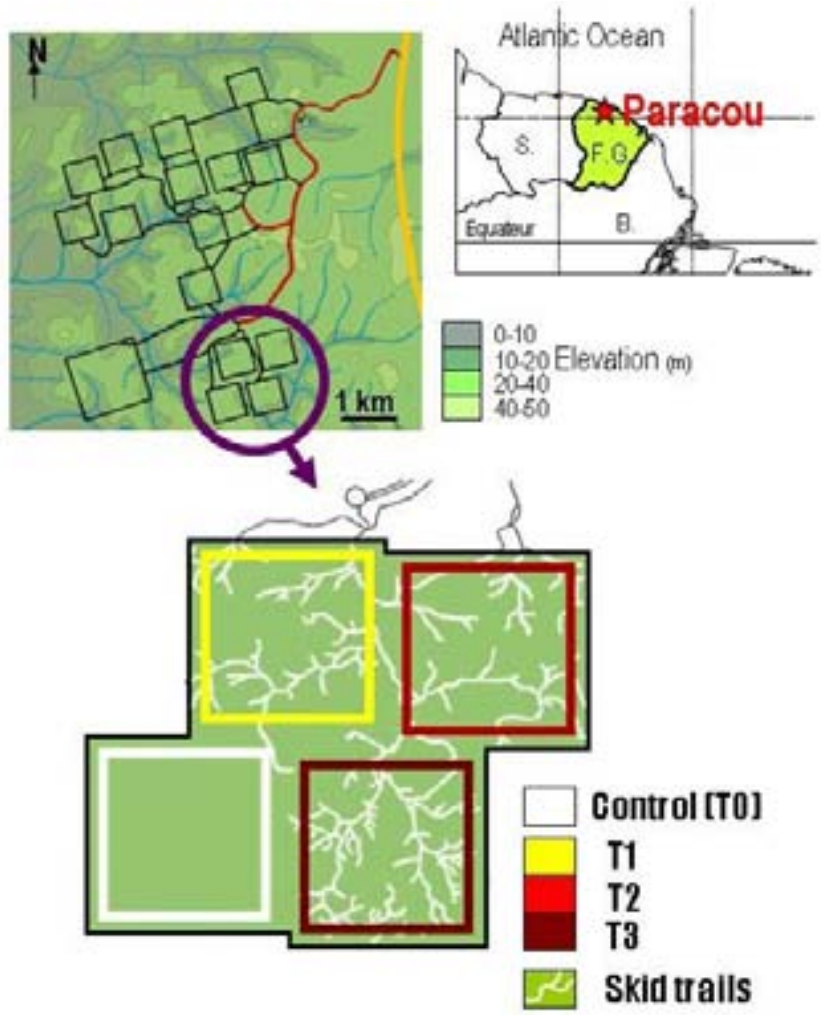
How do the spectral properties of the canopy captured by satellite-based images relate to its structure evaluated through hemiphots?

Method

Analyse relationships between **two groups** of variables,
derived from *satellite-based images* and *hemiphots*

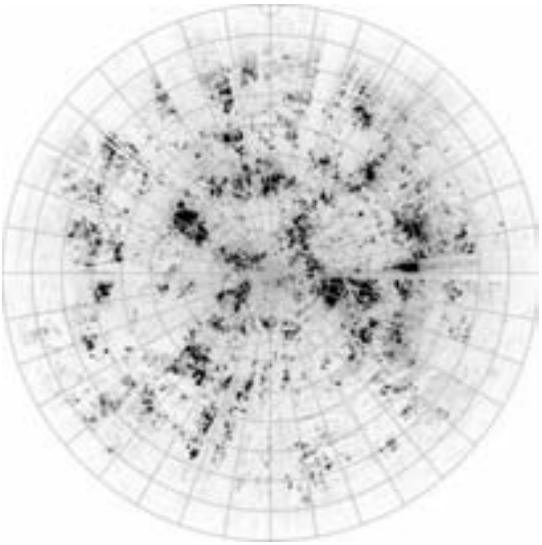
Study site and sampling design

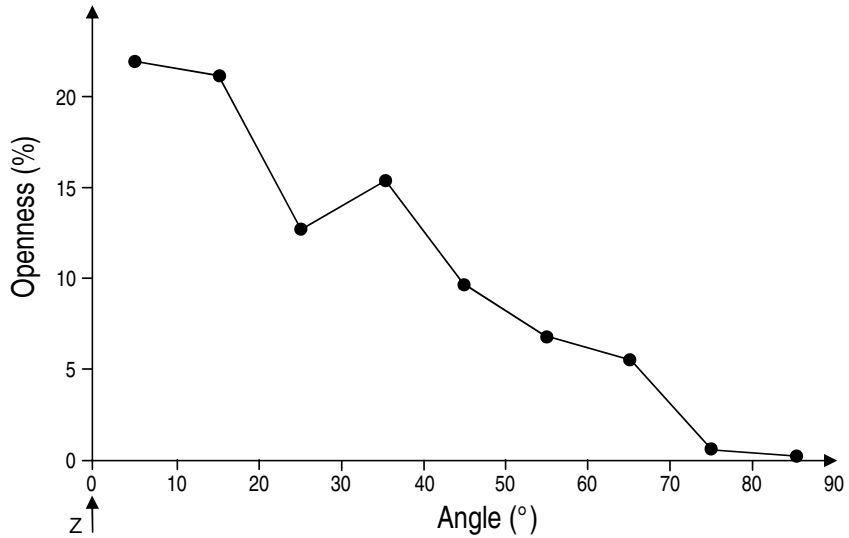
- **Study site:**
  - Paracou (French Guiana) in a *terra firme* rain forest,
  - 300 × 300 m permanent sample plots (PSP),
  - 3 silvicultural treatments (T1,T2,T3) in 1986-1988 (selective logging, poison-girdling) + control (T0),
  - digitalized maps of PSP limits, skid-trails (ST), logging damage (LD).
- **Sampling design:**
  261 points located in 1 *control* + *2 treated* plots (T1,T3).



Canopy structure

- Hemiphots at 1.5 m above ground level,
  with digital camera (Nikon Coolpix 995) and fish-eye,
- Imaging software: Gap Light Analyser (GLA 2.0, Frazer *et al.*, 1999),
- After exploratory analysis, 3 variables retained:
  - *PAI*: Plant Area Index,
  - CO_{20} and CO_{50}: canopy openness restricted to solid angles of 20° and 50°.





Ikonos images

Ikonos images of the study site (July 2002):
1 panchromatic band +
4 monochromatic bands: blue, green, red, near infra-red (NIR)

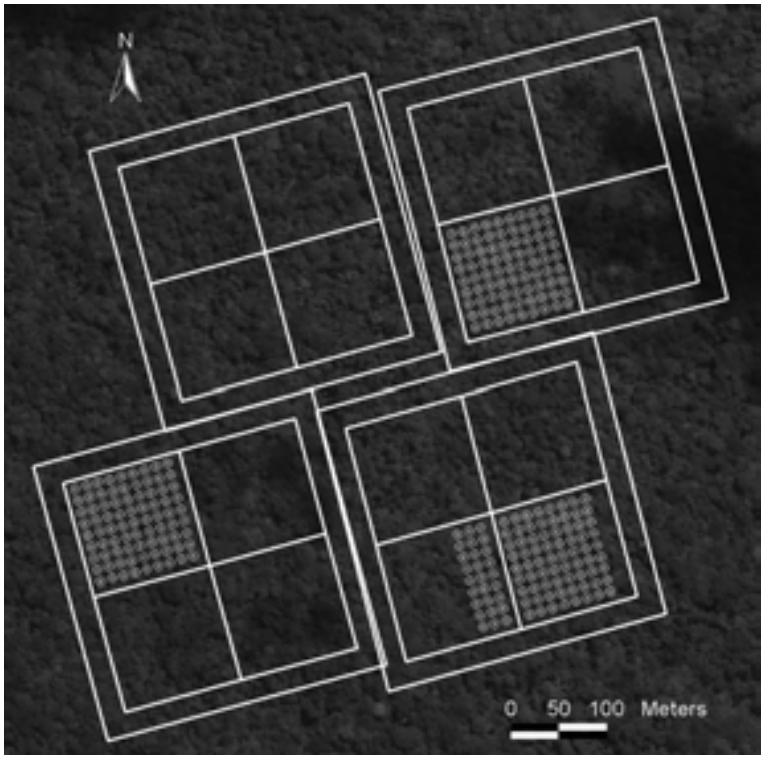
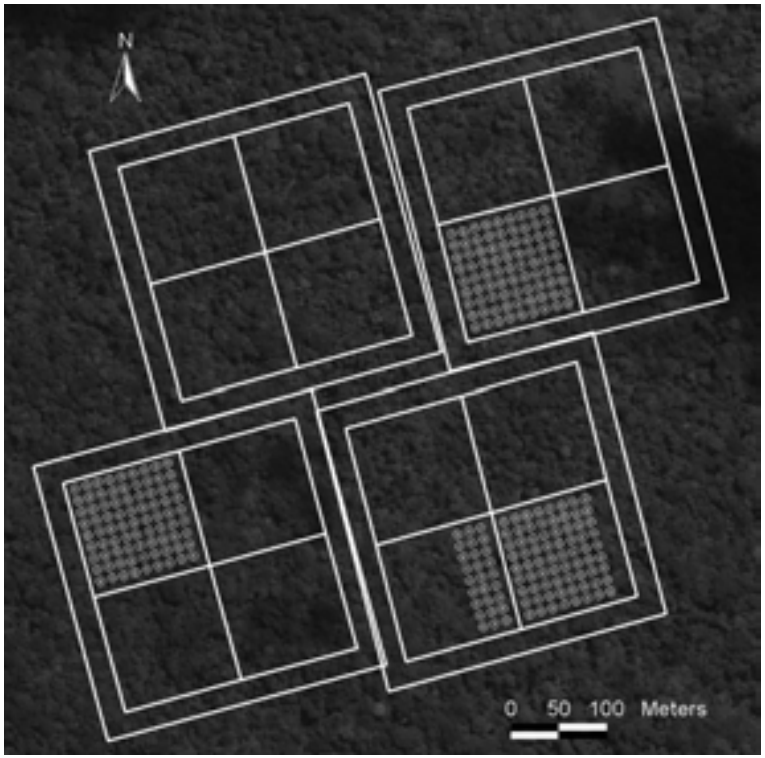


Figure: Image of the plots (Ikonos, panchromatic band)

Band		λ (μm)	*Reso.* (m)
pan.		$0.45 - 0.90$	1
mono.	blue	$0.45 - 0.52$	4
	green	$0.52 - 0.60$	
	red	$0.63 - 0.69$	
	NIR	$0.73 - 0.90$	

Table: Wavelength range (λ) and spatial resolution of Ikonos bands

Image treatment



1. *Oversampling* of monochromatic bands at 1 m-resolution,
2. Positioning of *sampling points* on the images,
3. Elimination of points under *cloud cover* ($n = 9$),
4. *Pixel selection* (5m-circular buffer) around each point,
5. Statistics calculation (*mean* and *standard deviation*) based on digital numbers.

Variables measuring spectral properties

After exploratory analysis, 3 variables retained:

- Mean values in the *green band*: Gre_m,
- Mean *Normalized Difference Vegetation Index*: $NDVI_m = \frac{R_{NIR} - R_R}{R_{NIR} + R_R}$,
- Standard deviation in the *panchromatic* band: Pan_s.

Statistical analysis

- 2 groups of 3 variables,
- Exploratory analysis:
  - **Univariate** distributions and **bivariate** relationships among variables,
  - Non-parametric **multiple comparisons**:

    Effect of silvicultural treatment, skid-trails, logging damage?

- **Multivariate** relationships: canonical correlation analysis (CCA)

  $\rightsquigarrow$ *seeks independent linear combinations of variables in one group best correlated with independent linear combinations of variables in the other group* (Thioulouse *et al.*, 1997).

Variables distribution I

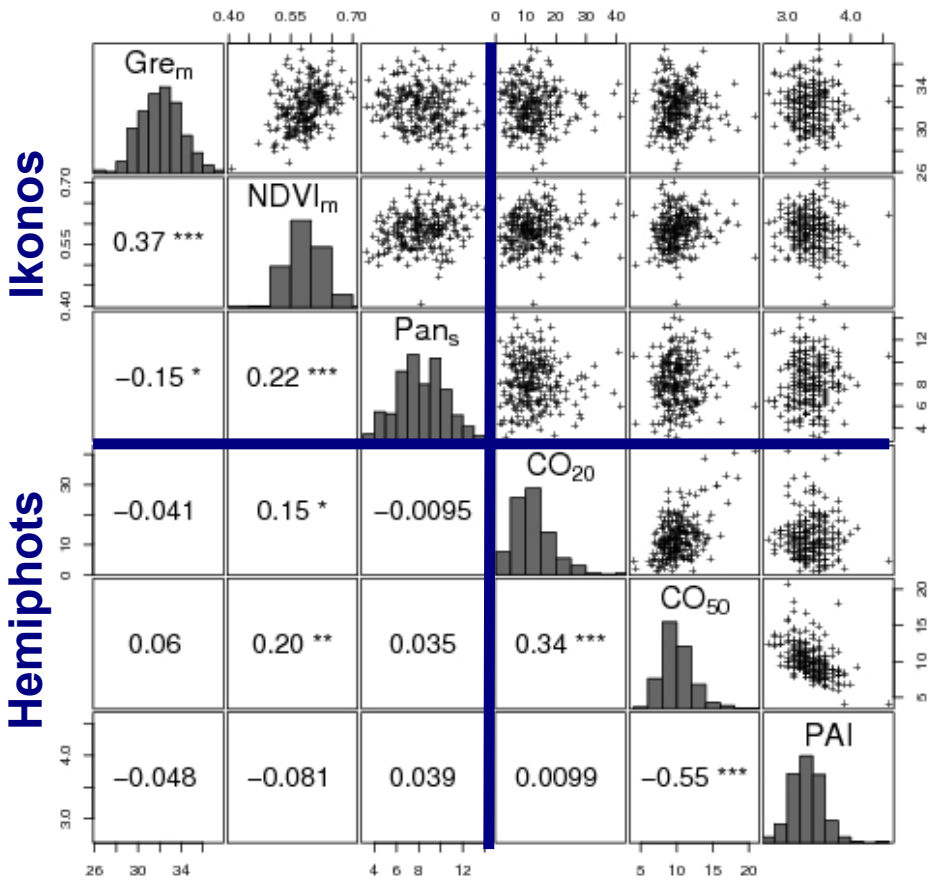
Summary

	Ikonos			Hemiphots		
	Gre_m	$NDVI_m$	Pan_s	$C0_{20}$	$C0_{50}$	PAI
minimum	26.3	**0.408**	3.27	1.5	4.1	2.7
mean	32.1	0.587	8.31	12.5	10.2	**3.4**
maximum	37.5	**0.701**	14.15	41.6	20.8	4.6
c.v.	0.06	0.07	**0.26**	**0.54**	**0.22**	0.07

- $0.4 < NDVI_m < 1$: forested area,
- PAI: low values,
- Variability:
  - CO_{20}: most variable,
  - CO_{50}, Pan_s: intermediate,
  - PAI, Gre_m, $NDVI_m$: low.

Variables distribution II

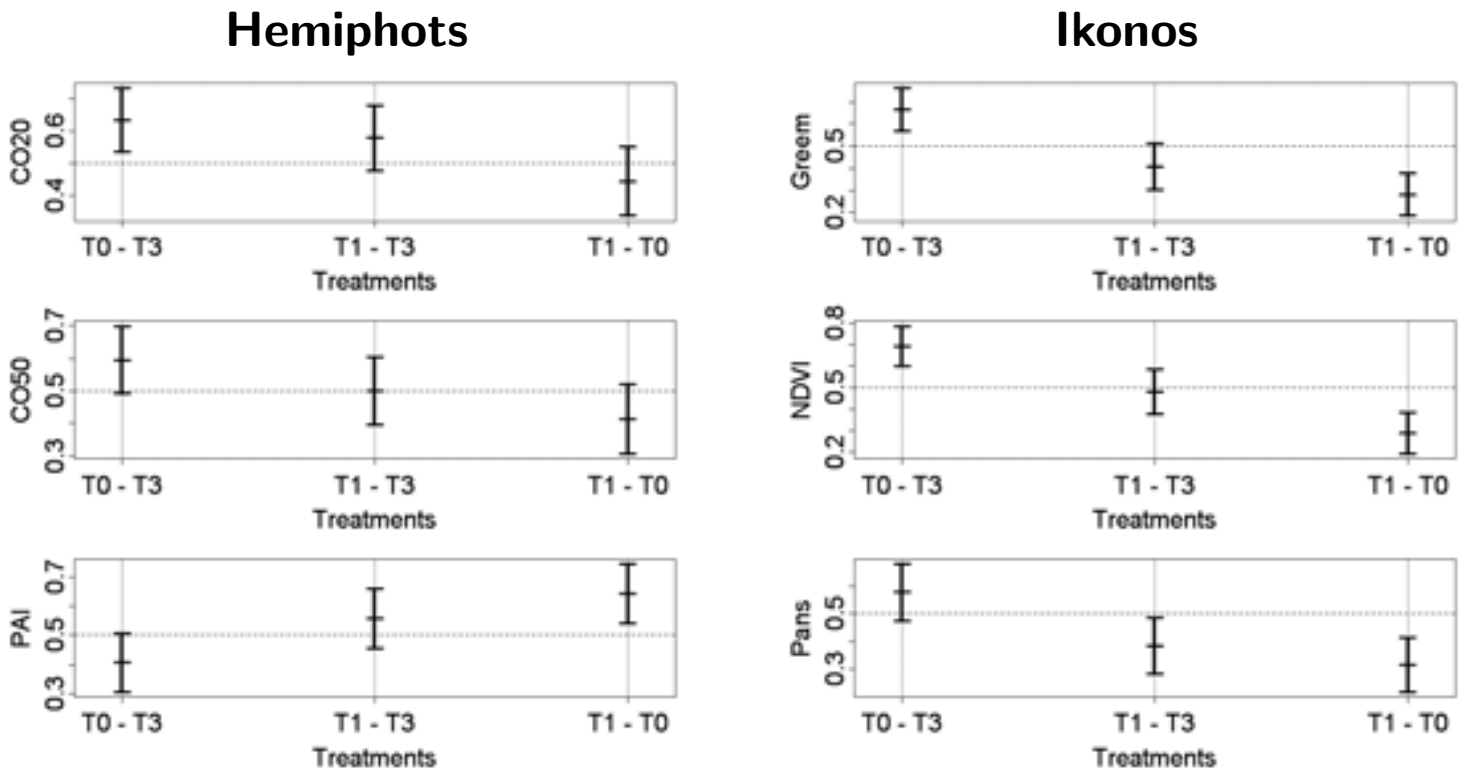
Univariate and bivariate distributions



- Within groups: high and significative correlations,
- Between groups: lower but some significative correlations.

Multiple comparisons I

Effect of silvicultural treatment



With ↗ disturbance intensity (T0<T1<T3):

- Hemiphots: ↗ canopy openness, ↘ Plant Area Index (PAI).
- Ikonos: ↗ Gre_m, $NDVI_m$, Pan_s.

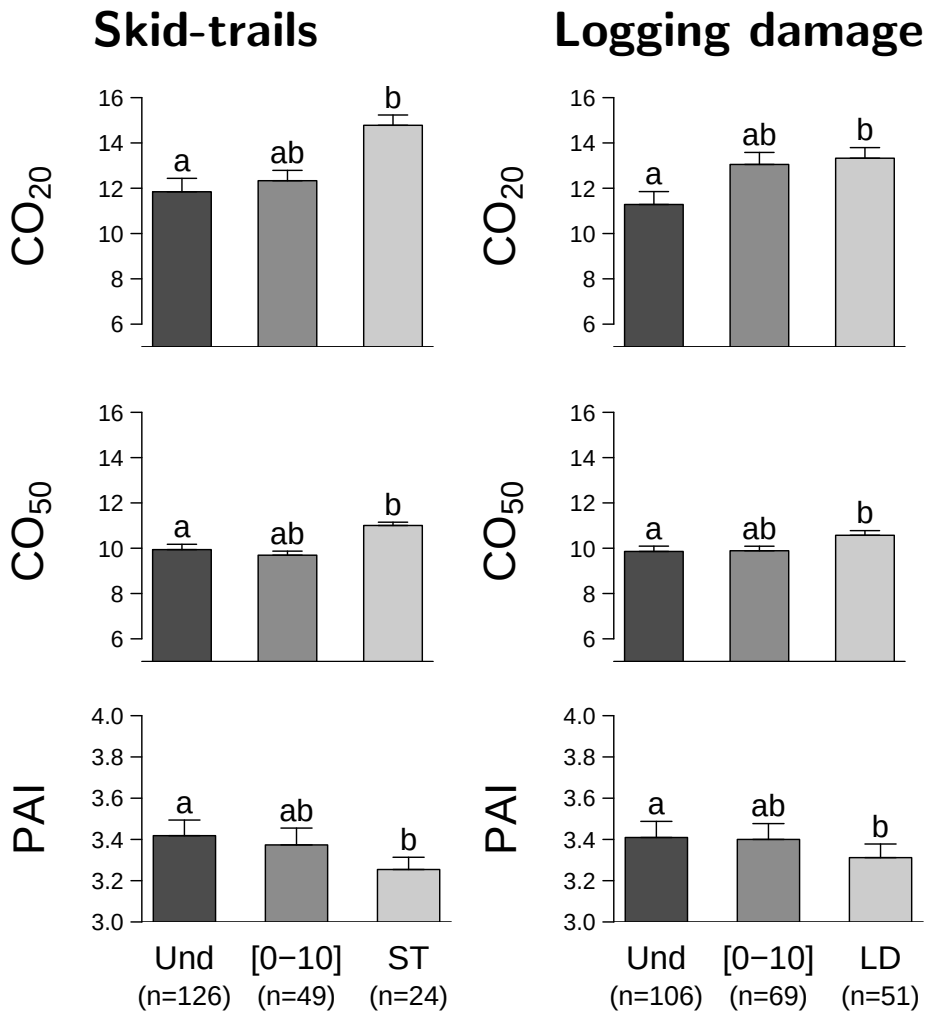
Multiple comparisons II

Canopy openness and PAI: effect of skid trails (ST) and logging damage (LD)

GIS masks:

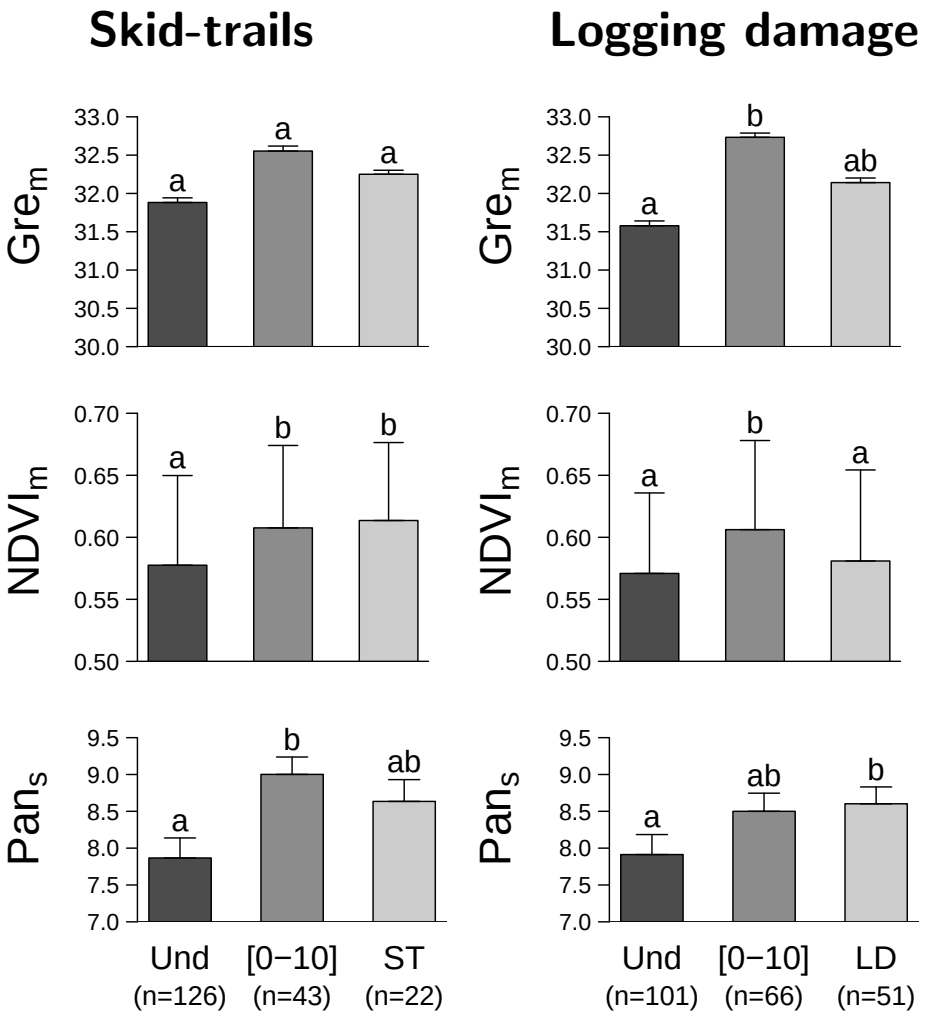
⋆ Und: *undisturbed*,
⋆ [0 − 10]: *10-m buffer around disturbed areas (ST+LD)*,
⋆ ST: *skid-trail*,
⋆ LD: *logging damage*.

- Disturbed / undisturbed zones:
  ↦ Canopy openness ↗
  ↦ PAI ↘
- Buffer effect:
  different between skid-trails and logging damage



Multiple comparisons III

Spectral properties: effect of skid trails (ST) and logging damage (LD)

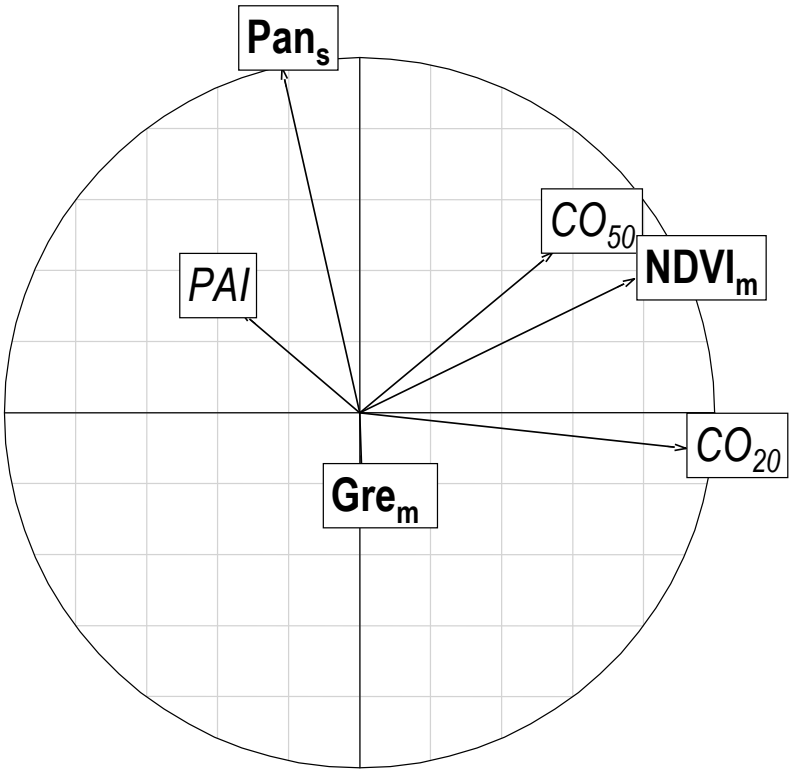


Same masks used

- Gre_m: weakly discriminating, buffer effect / LD,
- $NDVI_m$: higher on ST, buffer effect / ST, LD,
- Pan_s : higher on LD, buffer effect / ST.

Canonical Correlation Analysis I

Correlations between axes:
1) 0.19
($p < 0.01$, Spearman rank correlation test),
2) 0.14 ($p < 0.05$),
3) 0.07 ($p > 0.05$).



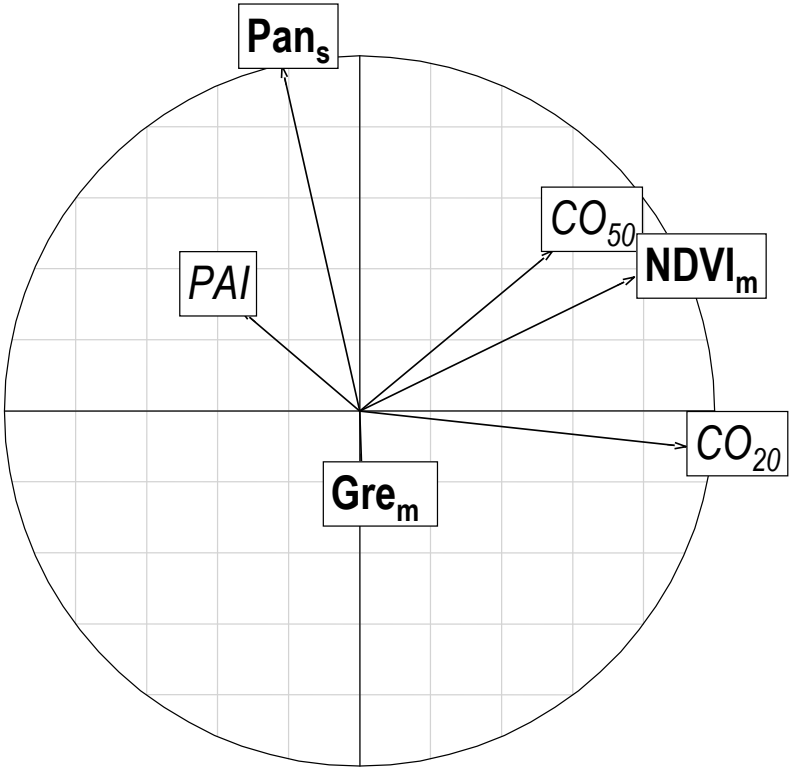
From *hemiphots* variables:

- First axis: gradient of *canopy openness*,
- Second axis: gradient of *heterogeneity* in canopy structure (clumping?).

Canonical Correlation Analysis II

From **Ikonos** variables:

- Gradient of NDVI correlated with openness
  $\Rightarrow \nearrow$ photosynthetic activity in more open sites,
- Second axis:
  heterogenity measured in Pan_s,
  < 0 correlation with Gre_m
  $\Rightarrow$ roughness, shading, debris?



Summary - Discussion

- Characterized canopy structure and spectral properties of a tropical forest canopy at very local scale,
- Persisting disturbance signal in canopy structure,
- Common information shared by the two media,
  - *Hemiphots*: canopy openness and PAI,
  - *Ikonos images*: correlated spectral properties,
- Two significantly correlated axes:
  - Canopy openness, mostly correlated with NDVI,
  - Heterogeneity in structure, may be due to clumping

Conclusion and perspectives

$\rightsquigarrow$ First attempt to relate *fine-scale spectral properties* of a tropical forest canopy with *field-based measures of canopy structure*.

However, a number of limits and thus . . . perspectives!

- Improve description:

  $\star$ spectral properties:
  calibration, localisation,

  $\star$ canopy structure:
  LAI instead of PAI, proportion of trunks, branches,. . .

- From quantity to quality of light?
- Add ecological data:

  species identity, foliage attributes.

- Adress temporal variability?

. . . a promising field!?

The end

Thank you!